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DESIGN BASIS FOR A NEW TRANSONIC WIND TUNNEL.(U)

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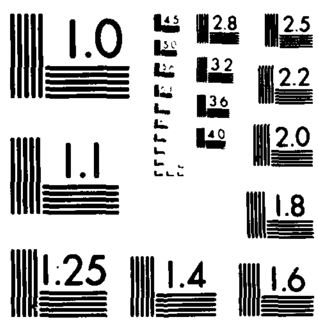

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J.B. WILLIS and N. POLLOCK

SUMMARY

The existing ARL Transonic Wind Tunnel, which is the largest such tunnel in Australia, has severely limited testing capabilities due to a low test Reynolds number and an inadequate test section size. These deficiencies are becoming more acute as military aircraft performance capabilities increase. For current fighter aircraft, the ratio of tunnel test to flight Reynolds number is about 1:100 and the extrapolation of tunnel data to flight carries a high risk of serious error and for some conditions is not possible at all. The small test section size limits the scale of the models which can be tested. The difficulty of machining small models to the required accuracy produces excessive manufacturing times. Moreover, it is not possible to incorporate remotely adjusted control surfaces. These two factors severely restrict tunnel productivity.

Various new types of transonic wind tunnels have been suggested overseas, and these are discussed briefly. Configurations suitable for local needs are considered, and the basic specification for an appropriate wind tunnel is provided.

Given adequate support, it should be possible to build and commission a suitable new wind tunnel in about five years, at a cost substantially less than that of a single military fighter aircraft.

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16.Abstract

The existing ARL Transonic Wind Tunnel, which is the largest such tunnel in Australia, has severely limited testing capabilities due to a low test Reynolds number and an inadequate test section size. These deficiencies are becoming more acute as military aircraft performance capabilities increase. For current fighter aircraft, the ratio of tunnel test to flight Reynolds number is about 1:100 and the extrapolation of tunnel data to flight carries a high risk of serious error and for some conditions is not possible at all. The small test section size limits the [illegible] of the models which can be tested. The difficulty of machining small [illegible] to the required accuracy produces excessive manufacturing times. [illegible], it is not possible to incorporate remotely adjusted control surfaces. These two factors severely restrict tunnel productivity.

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CONTENTS

NOTATION

R	Reynolds number
M	Mach number.

1. INTRODUCTION

For many years the existing ARL transonic wind tunnel has been inadequate to meet all Australia's transonic aerodynamic testing needs. With the appearance of a new generation of military aircraft this problem is rapidly becoming more acute.

This memorandum briefly reviews the history of the existing tunnel, outlines its shortcomings and discusses possible future developments. It is shown that the existing facility cannot be developed to satisfactorily meet the testing needs of the next 20 years.

Australia's transonic aerodynamic testing needs are briefly reviewed and an outline of the capabilities required of a new test facility is given. The various new transonic tunnel concepts developed in recent years are briefly surveyed to determine their suitability for local requirements.

2. HISTORICAL BACKGROUND OF THE ARL TUNNEL

The existing transonic tunnel was built in the early 1940s. It was designed to function as a variable pressure subsonic high speed tunnel and used a 2 stage contra-rotating fan. Maximum power input was 110 kW which was inadequate. About 1950, a "Merlin" aircraft engine and a new two stage compressor were fitted and proved that the tunnel was aerodynamically sound, although more cooling was needed to cope with the increased power, and the "Merlin" introduced many operational difficulties. In 1956, the tunnel was shut down for nine months and rebuilt as a transonic tunnel with the present electric drive of about 1650 kW, 2600 kW of cooling, new gear box, contraction, test section of increased size, sliding first diffuser access door, extended top hatch etc. It was intended to fit auxiliary suction, but despite a supporting recommendation by CAARC, lack of funds prevented this being done. Auxiliary suction would have provided increased Reynolds number, apart from reducing shock reflections and providing other benefits. About 1961, the present four stage compressor was installed.

In 1963, an intermittent blowdown transonic tunnel was proposed[1], which would have provided more adequate Reynolds numbers and test section size, and which would have made Australian facilities comparable to those of countries like India. This proposal was also rejected. Had this tunnel been built, it would have come into operation around 1970, and would have gone a long way towards meeting current needs.

3. INADEQUACIES OF THE EXISTING TUNNEL

The existing tunnel suffers from several inadequacies, as would be expected for a tunnel designed over forty years ago. In

1964, A.K. Wrigley, then Chief Aerodynamicist G.A.F., commented on the limitations of the ARL tunnel (Ref. 2). These included the low test Reynolds number, the difficulties associated with small models and the output of "raw" unplotted data. The last problem was overcome in 1968 with the installation of a dedicated mini-computer system.

To give some indication of the size of the ARL tunnel the following table of existing transonic wind tunnels, most of which have been operating for about 20 years, is reproduced from Pope and Goin (Ref. 14).

TABLE 1

Country	Tunnel	Test Section	Input H.P.
U.S.	AEDC	16'x16'	100,000*
U.S.	NASA AMES	11'x11'	200,000
U.S.	NASA AMES	16' Circular	27,000
U.S.	NASA LANGLEY	15.5' Octagonal	60,000
U.S.	BOEING	8'x12'	54,000
U.K.	ARA	8'x9'	38,000
U.K.	RAE	6'x8'	20,000
Netherland	NLR	5'4x6'8"	20,000
France	ONERA	25' Circular	110,000

* Later figures for this tunnel give a total installed power of 395,000 H.P.

By contrast the ARL tunnel has a test section 0.81mx0.53m (32"x21") and a power input of 2,500 H.P. It should be noted that even countries like India and Japan have transonic tunnels many times larger than the ARL tunnel.

In the following sections specific inadequacies of the present facility are described.

3.1 Reynolds Number

In the 1960s, most transonic testing in Australia was for Jindivik, bombs, Ikara etc. and for these devices the available R was more or less adequate. Even so, considerable skill and experience was needed to simulate higher R flow, and much tunnel time was used trying to ensure that these techniques were satisfactory.

More recently, the demand has been for data on Mirage and F111 aircraft and on the carriage and release of stores from these aircraft. Here the obtainable tunnel test R is about 1/100th of that reached in flight (Fig. 1) and extrapolation from tunnel to flight is always uncertain and often impossible. For reasonably confident extrapolation to flight conditions a test R of at least a quarter of the flight value is desirable (Ref. 3). If it is intended to support the design of high performance aircraft, test facilities with R capabilities approaching flight values are desirable and such tunnels are currently planned or being built in the U.S.A. (Ref. 4) and Europe (Ref. 5).

The types of measurements required in recent times have included flutter work, dynamic derivatives, stores dropping (not possible in the present tunnel), buffet investigations and, of course, normal static force and pressure measurements. The main areas of work expected in the future are provision of data banks for operational aircraft, provision of data on aerofoil sections, and provision of data related to manoeuvrability and high incidence effects - the latter two areas are also likely to be active research areas.

Since any new transonic tunnel in Australia would be the only one suitable for testing complete aircraft models, it should be an all purpose facility and have a test Reynolds number 30 to 40 times that of the existing tunnel. It must be capable of making all the types of measurement mentioned above including those requiring considerable time. Although the test Reynolds number specified should be adequate for many years it would be wise to provide in the design for a possible future increase unless this produces an unacceptable rise in cost. Any new tunnel must have high productivity with limited manpower and be simple to operate and maintain.

3.2 Test Section Size

The existing tunnel test section is 533 mm by 813 mm with slotted walls. Since for transonic testing, the blockage ratio (model frontal area divided by test section area) should be 1% or less, models are small and must be made to high accuracy in high tensile steel. Each complete model requires a new strain gauge balance tailored to fit inside the model. Remote actuation of controls is impossible, and they must be detached and refitted each time a different setting is needed. This requires letting the tunnel up to atmospheric pressure by bleeding in dry air, adjusting the model, and then reducing tunnel pressure, and redrying if necessary before tunnel testing can proceed. Also, in some cases, the only method of doing tail and elevator effectiveness, requiring say, 6 elevator angles and 6 tail angles, is to make 36 assemblies. Manufacture of fins, attachment of stores, etc. all become major tasks, and balances are fragile and easily damaged.

Because small models have little metal for attachment purposes, and require high accuracy, design, drawing and manufacture times are large and costs high. These times, plus the tunnel delays already mentioned, cause tunnel productivity to be low.

It is considered that there is an optimum model size for speed and ease of construction and that the test section size of a new tunnel should be largely determined by model making considerations. Small models require high precision, long manufacturing times and high costs; large models require very large machines, cranes for lifting them, and again are expensive. At present, a model span of about 1.1 m seems to be near optimum. Experience has shown that the required dimensional tolerances for a model of this size (±0.05 mm) (Ref. 6) can be conveniently achieved on current numerically controlled machines and the individual model components would be of a suitable size for mounting on these machines.

This model size leads to a test section about 2 m square. For two dimensional testing a narrower test section would be required and both configurations should be available in an all purpose tunnel. In the past, every new missile, aircraft proposal or design, has started with a request for two dimensional aerofoil tunnel data. This will continue, and the importance of two dimensional testing should not be underestimated.

4. FURTHER DEVELOPMENT OF EXISTING TUNNEL

Further developments of the existing tunnel to overcome the known deficiencies have been under continuing consideration but to date no really worthwhile possibilities have become evident.

The test section size cannot be further increased unless half the tunnel circuit and the compressor are also replaced.

By fitting a two speed gearbox in the tunnel drive an R increase of about 2 could be realised at subsonic speeds while by fitting auxiliary suction an R increase of similar magnitude could be obtained at supersonic speeds. This gain in Reynolds number is insignificant compared with what is needed and the cost, estimated to be about $300K, would be considerable.

The use of adaptive walls and/or the development of more precise tunnel corrections would allow slightly larger models to be used but again the Reynolds number gain is insignificant.

The conversion of the tunnel to cryogenic operation is the only approach which would produce a Reynolds number increase of the required magnitude. Unfortunately such a conversion would require the complete replacement of the tunnel circuit, compressor etc. due to the incompatibility of the existing materials with low temperature operation. This approach would be equivalent in cost and effort

to building a completely new tunnel and as discussed later, for a new facility, cryogenic operation would probably not be the correct choice.

5. SURVEY OF POSSIBLE NEW TUNNEL CONFIGURATIONS

In order to assess the suitability of the many available tunnel configurations, a basic tunnel specification to meet local needs is required. From section 3, such a specification emerges viz.

1. A main test section about 2 m x 2 m with a second test section or test section inserts for two dimensional measurements.

2. The test Reynolds number to be 30 to 40 times the existing value and therefore within a factor of 2 or 3 of flight for F111 and Mirage aircraft.

3. The tunnel must be capable of making all of the following types of measurement:

   (a) Static forces and moments.

   (b) Steady pressure distributions.

   (c) Dynamic force and moment derivatives.

   (d) Oscillatory pressures.

   (e) Flutter.

   (f) Buffet.

   (g) Stores release, preferably free dropping as well as captive trajectory.

4. The tunnel should have high productivity and be convenient to operate with a minimum of staff.

5. The tunnel configuration should be such that the engineering requirements are within the current experience of Australian industry. The development of new technology is time consuming and expensive.

6. Over the years, a considerable body of skill, experience and knowledge has been accumulated in operating the existing transonic wind tunnel. It is therefore desirable that any new tunnel be designed so that these skills can be directly exploited. Designs which depart radically from the existing concept would require new skills and experience to be built up. This could significantly delay the commissioning of the new tunnel.

In the following sections the various tunnel types currently in use, or proposed, are assessed with respect to the above requirements.

5.1 Continuous Tunnel - Conventional

This type of tunnel has been the first choice for most of the history of experimental aerodynamics and most of the major transonic tunnels in the world today of this type. The major advantages of this type of facility are:

(a) Due to the virtually unlimited run times available there are no constraints placed on the types of tests that can be carried out. Inherently time consuming tests such as flutter and buffet measurements and surface flow visualisation can all be carried out easily.

(b) Due to the absence of time limitations, instrumentation, tunnel speed control and model attitude control are relatively simple.

(c) With proper aerodynamic design using well known and documented procedures very good test section flow quality can be obtained.

(d) Many well established tunnels are available which could be used as models for the new facility. This could significantly reduce the design cost (to near zero if an existing tunnel was simply copied) and the technical risk.

The only significant disadvantage of this type of tunnel is its high cost when very-high Reynolds number capabilities are required. Recent studies in the U.S.A. and Europe have shown that continuous flow conventional tunnels are not economically practical when full scale Reynolds numbers are required at transonic speeds. However the tunnel being sought here is not a very high R facility and corresponds to the many already well established tunnels.

5.2 Continuous Cryogenic Tunnel

Since the speed of sound is proportional to the square root of the absolute temperature, transonic operation is possible at low velocities if the temperature is sufficiently reduced. As tunnel drive power is proportional to the cube of the velocity, very small power inputs are required at low temperatures. To achieve low temperatures, nitrogen is used as the working fluid and liquid nitrogen is continuously injected. To maintain a constant operating pressure cold gaseous nitrogen is continuously vented. The vented

gaseous nitrogen is then re-liquified with an on-site liquifaction plant. Simply venting the cold gas to the atmosphere would involve an effective energy loss which would significantly reduce the economic attractiveness of the system. It should be noted that despite this type of tunnel being nominally continuous it is in reality a stored energy intermittent device. The drive power is low but the effective cooling power is so high that the continuous production of liquid nitrogen in sufficient quantities to operate the tunnel is impractical. Individual run times will in general be long enough to permit all the tests that can be carried out in a conventional tunnel but the overall tunnel productivity will be limited by its intermittent operation. A good description of the cryogenic tunnel concept is presented in Refs. 7 and 8. More detailed information on the concept can be found in Refs. 9-11.

The advantages of the continuous cryogenic tunnel are:

(a) The test Mach number and Reynolds number can be varied independently over a wide range.

(b) For very high R tunnels, the capital cost of cryogenic tunnels will be lower than conventional tunnels. For more moderate R, and in Australia, the cost would almost certainly be higher.

(c) Slightly lower operating power cost to conventional continuous tunnel.

The significant disadvantages are:

(a) Limited productivity due to inherently intermittent operation.

(b) The extreme difficulty of designing and manufacturing models and instrumentation (strain gauge balances, pressure measuring equipment etc.) which will operate satisfactorily in a cryogenic environment. These problems are regarded as difficult in the U.S.A. and Europe where a considerable background of cryogenic technology is available from space programs. In Australia a verv long lead time and large expenditure would be required to acquire the necessary technology.

(c) Cryogenic tunnels pose serious safety problems (Ref. 12). Condensation of oxygen in the circuit may lead to an explosion hazard, the accidental release of liquid or gaseous nitrogen may endanger the surrounding area and special provision must be made for air conditioning and warming the test section before staff can adjust the model.

(d) Despite the commitment of the U.S.A. and Europe to cryogenic tunnels some doubts still remain about the accuracy with which cryogenic nitrogen flows simulate ambient temperature air flows (Ref. 13).

(e) Many test techniques which are readily available in ambient temperature tunnels, eg. surface oil flow investigations, will require prolonged development to make them function at cryogenic temperatures.

5.3 Intermittent Blowdown Tunnel

In this type of tunnel air from a high pressure reservoir is passed through a throttle valve into a settling chamber with some temperature stabilising mechanism then through a contraction and test section to atmosphere. This type of tunnel has been used primarily where low capital cost and flexible operation - subsonic, transonic and supersonic capability - was required. Canada (Ref. 16) and India have major blowdown tunnels and many aircraft companies also have facilities of this type. The major advantages of blowdown transonic tunnels are:

(a) Low capital cost.

(b) The possibility of using the same basic tunnel for subsonic, transonic and supersonic testing.

(c) The high pressure air storage required could provide the power source for a number of different tunnels and test facilities eg. engine test cells.

(d) The technical risk involved in designing a blowdown tunnel would be low due to the large number of existing facilities which could be used for guidance.

The major disadvantages are:

(a) This type of tunnel is very energy inefficient and the practical limitations on installed compressor power tends to lead to very low productivity. Operating times tend to be a few minutes or tens of minutes per day.

(b) The test section flow tends to be unsteady, turbulent and noisy.

(c) The individual run times are short particularly for high Reynolds number operation. This leads to difficulties with some types of measurement.

5.4 Induction of Injection Drive Tunnel

In this type of tunnel high pressure air from a storage reservoir is injected into the tunnel in such a way that a larger mass flow of lower velocity is induced through the test section. These tunnels can be either closed circuit or open circuit with atmospheric inlet and exhaust. This type of drive is most suited to subsonic and transonic operation since sufficient pressure ratio to establish supersonic flow is not easily obtainable. Considerable development has been carried out on this type of tunnel in recent years (Paper 1 of Ref. 15 and Paper 4 of Ref. 18). However very few such tunnels are actually in use.

The advantages of this type of tunnel are:

(a) Reasonable capital cost.

(b) Availability of compressed air storage for other purposes.

(c) Somewhat higher energy efficiency and run times than the blowdown tunnel.

The disadvantages are:

(a) Significant technical risk due to the small number of induction drive tunnels currently in service.

(b) High test section turbulence (for closed circuit type) and noise level.

(c) Significantly lower productivity than a continuous tunnel due to intermittent operation.

5.5 Evans Clean Tunnel

This tunnel drive system was developed during the 1970s as a serious contender for a new European transonic facility before cryogenic operation was selected (Ref. 5). The concept is described in Paper 35 of Ref. 17, Paper 3 of Ref. 18 and Ref. 15.

The concept basically consists of a conventional closed circuit without fan and with a long cylindrical chamber preceeding the contraction. This chamber is fitted with a piston which is used to push the slug of air in the chamber through the test section. The piston is driven by an ingenious system of cables and auxiliary pistons operating in vacuum cylinders. The tunnel run is started by opening a valve downstream of the prepressurised test section and appropriately accelerating the main drive piston to cancel the resulting expansion wave. The run terminates when the main piston reaches the end of its travel.

The major advantages of this tunnel are:

(a) Potentially very high quality (low turbulence and noise) test section flow. The flow quality obtainable should be better than for conventional continuous tunnels since air disturbed by the model and drive system is not recirculated through the test section.

(b) The energy efficiency should be superior to any of the other stored energy concepts therefore operating costs should be low.

The disadvantages are:

(a) The tunnel design involves considerable mechanical complexity and could prove to be very expensive to build.

(b) No operating tunnel of this type exists and active development work appears to have ceased. The technical risk involved in building such a tunnel would be considerable.

5.6 Ludwieg Tube

This concept is described in Ref. 19, Papers 29 and 30 of Ref. 17, Paper 2 of Ref. 18 and Ref. 15. The tunnel consists of a long pressurised charge tube which is separated from a test section by a diaphragm or quick acting valve. When the valve is opened a rarefaction fan propagates up the charge tube and shock is blown through the test section. After this starting transient a steady test section flow occurs until the expansion reflected from the far end of the charge tube comes back to the test section. The run time is obviously a direct function of charge tube length and practical tunnels of this type have typical run times of a few hundred milliseconds. A number of small Ludwieg tube tunnels are in use around the world, primarily for research purposes and one major development facility exists (Ref. 20) which is believed to have the highest Reynolds number capability of any existing tunnel. The brief specifications of this tunnel are: test section diameter 1 m, maximum Reynolds number 6×10^8 per m and run time 300 to 500 millisec.

The major advantage of this type of tunnel is extremely low capital cost for the Reynolds number capability obtained. The concept is capable of providing subsonic, transonic and supersonic flows.

The disadvantages are:

(a) The short available run times limit the types of test that can be carried out.

(b) The productivity would be low due to the very low run time to recharge time ratio obtainable with a practical compressor installation.

(c) Economically feasible Ludwieg tubes achieve their high Reynolds number by the use of very high stagnation pressures and small test sections. The resulting high aerodynamic loads make it virtually impossible to utilise the tube tunnels capabilities on representative aircraft models. The Marshall Space Flight Centre tunnel (Ref. 20) mentioned above is used for missile not aircraft testing.

5.7 Freon 12 Tunnel

The use of Freon 12 instead of air as a working fluid gives a considerable drive power reduction for a continuous tunnel of specified Reynolds number. This technique has been known for many years but has failed to gain any significant acceptance. The primary problem is that Freon is thermodynamically sufficiently different from air for test results to be very difficult if not impossible to interpret reliably.

5.8 Other Proposals

In sections 5.1 to 5.7 above, the major types of transonic tunnels in use or proposed are briefly reviewed. It should be recognized that various hybrid schemes are possible, in particular cryogenic operation could be added to most tunnel arrangements.

In addition to the arrangements discussed previously there are a number of other schemes of varying practicality which have not yet been developed to the stage where they can be considered as serious contenders for a new development tunnel. Some of the more interesting of these are:

(a) Cryogenic isentropic light piston tunnel (Ref. 21).

(b) Hydraulic compressor tunnel (Paper 5 of Ref. 8 and Ref. 15).

(c) Transonic shock tube (Ref. 22).

(d) Gasometer drive tunnel (Paper 4 of Ref. 23).

6. NEW TUNNEL PROPOSAL

The need in Australia is for an all purpose medium Reynolds number transonic tunnel and from the previous section it is clearly evident that a conventional continuous tunnel is the most appropriate configuration. The situation in the U.S.A. and Europe is different; they require very high Reynolds number facilities to complement a number of existing tunnels with capabilities similar to that of the tunnel proposed here.

An outline specification of the tunnel required becomes:

1. Closed return conventional continuous transonic tunnel.

2. Contraction ratio greater than 10:1.

3. Test sections 2 m x 2 m and 2 m x 1 m should be available with provision for porous and slotted walls. Auxiliary suction is required.

4. Operating pressure up to about 400 kPa.

5. Nozzle - simple, flexible.

6. $0<M<1.4$ operating range.

7. Input power = 50 MW total. Part of this will be needed for auxiliary suction, the quantity depending on nozzle and test section design.

8. Mach number at end of first diffuser to be low.

In addition to this brief specification, several important recommendations need to be made.

1. If economically reasonable, provision should be made for cryogenic operation at some future date. This would permit the tunnel R capability to be greatly increased at relatively low cost if it became necessary to meet new requirements arising early next century.

2. Data Handling
   The new tunnel should be equipped with its own dedicated on line computer. Such a system has been in use in the existing transonic tunnel since 1968 with great success, and this is now the standard world wide practice in wind tunnels.

3. National Importance
The tunnel should be regarded as a national, as well as defence, asset and should be available to the RAAF Academy, Universities and Institutes of Technology.

4. Tunnel Building Design
Tunnel staff should be accommodated in sound proofed offices close to the tunnel control room. Model fitting rooms, balance calibrating rigs, workshops and photographic dark room should also be located close to and on the same level as the control room.

5. Model Making
Model and balance design and manufacture should be carried out in a model shop located near the tunnel and under the control of tunnel staff. To ensure high productivity, model and balance production must be planned and carried out as an integral part of the overall tunnel program.

6. Design and Construction
Private contractors should be used, where possible, for design and construction as is common practice overseas. However, it is essential that overall project supervision be in the hands of local experienced wind tunnel personnel.

7. Cost
A number of tunnels exist which are similar to the present proposal, and design effort can be reduced by copying as and where appropriate. It is suggested that the ARA tunnel at Bedford is of particular interest. This tunnel has been in operation for many years, and is known to achieve the desired end using less costly techniques than many other tunnels. By these means, the cost can be considerably reduced without sacrificing essential performance. The estimated total cost is about $15 million at the present time.

CONCLUSIONS

The present ARL Transonic Wind Tunnel has been shown to have a test Reynolds number that is far too low for adequate testing of military aircraft. The small test section size makes model manufacturing difficult, costly and slow. Moreover the inability to fit control surface actuators in the small models limits tunnel productivity.

Consideration of local requirements against a background of recent tunnel developments overseas leads to the conclusion that a continuous flow conventional transonic tunnel with a test section of about 2 m by 2 m, and pressurised up to about 400 kPa would best meet local needs. Provision for future cryogenic operation, if not too costly, is also recommended.

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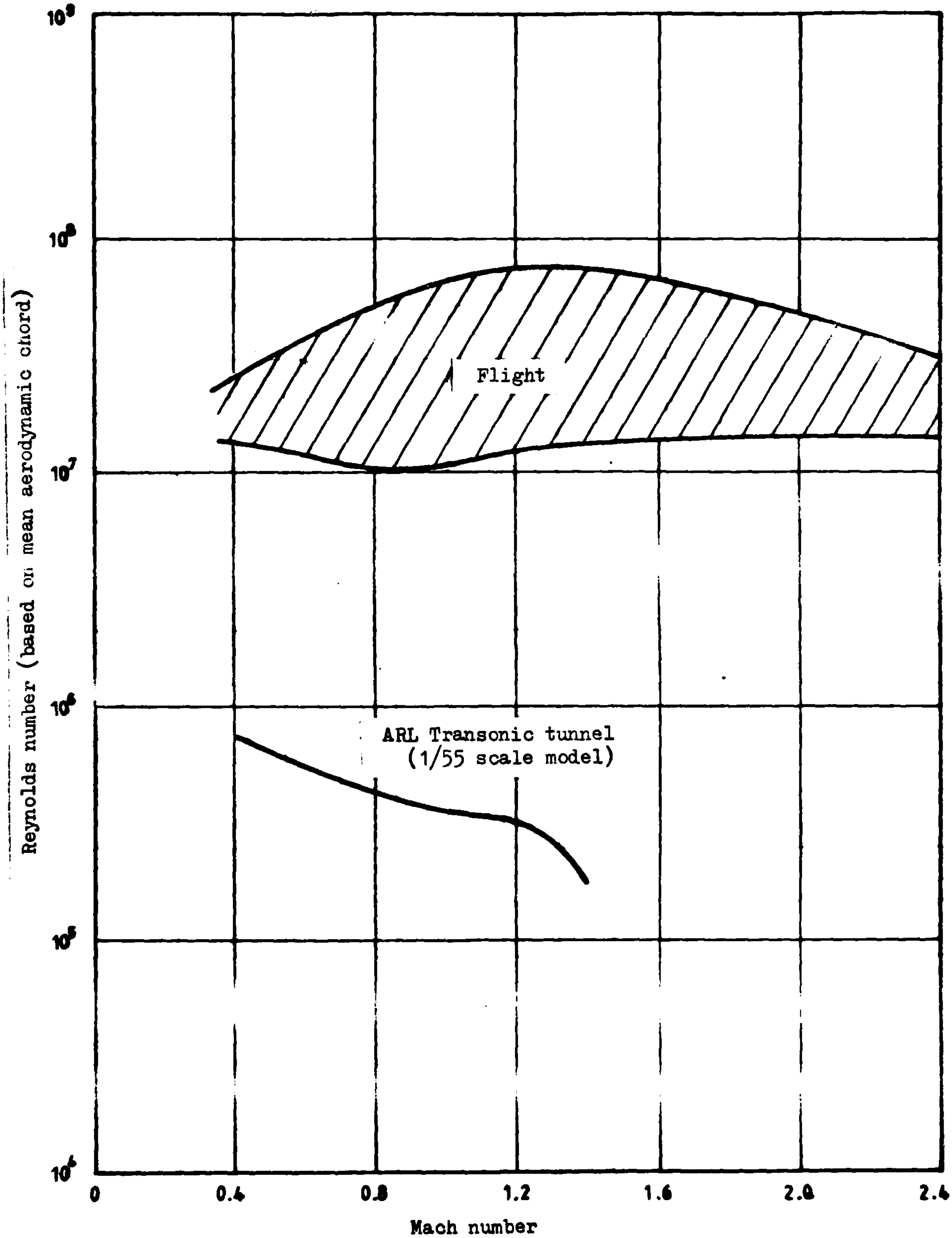

FIG. 1(a) COMPARISON BETWEEN FLIGHT AND A.R.L. TRANSONIC TUNNEL REYNOLDS NUMBERS FOR F111

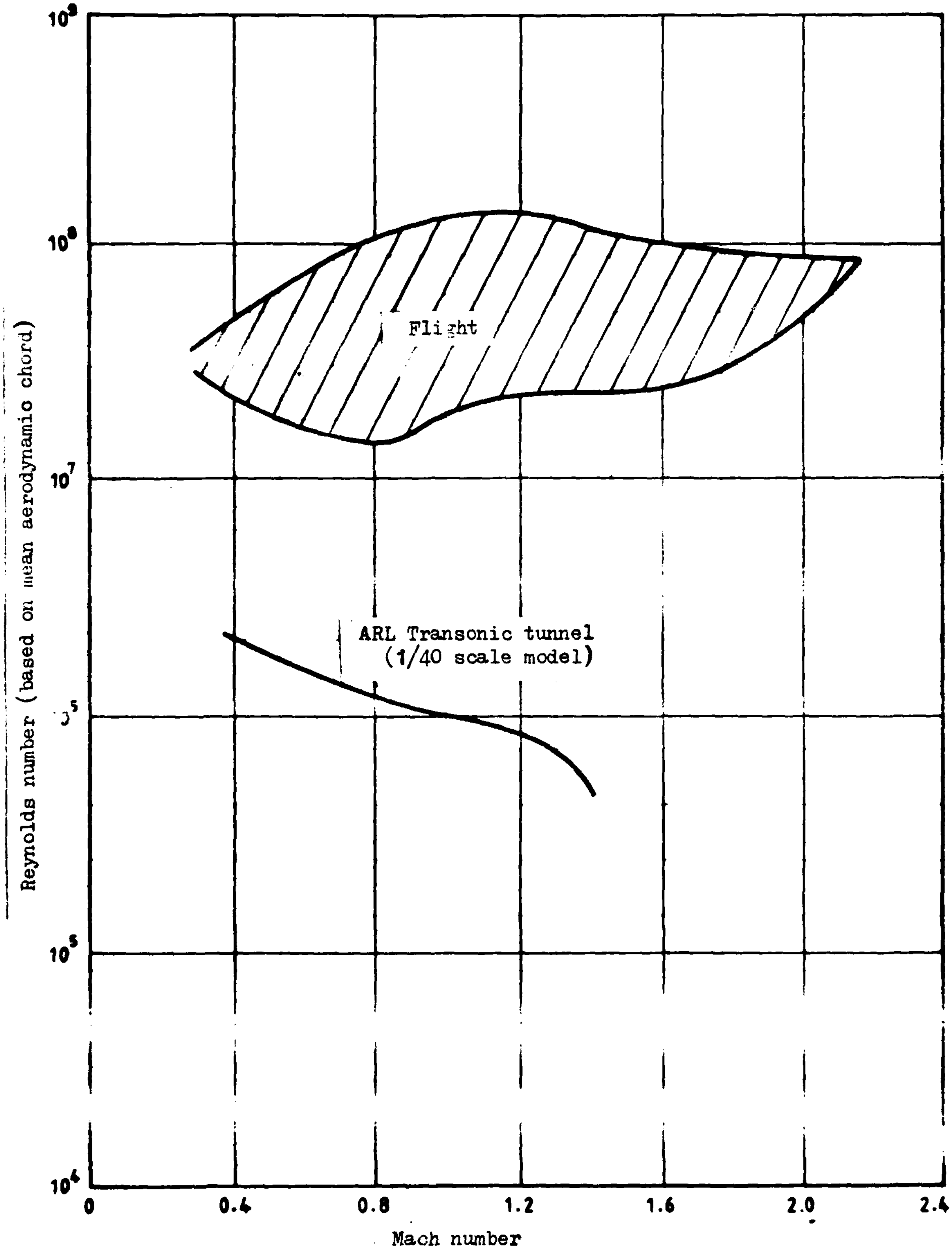

FIG.1(b) COMPARISON BETWEEN FLIGHT AND A.R.L. TRANSONIC TUNNEL REYNOLDS NUMBERS FOR MIRAGE

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